# Work on Liquid Argon at Fermilab

Stephen Pordes
Fermilab Institutional Review
June 6-9, 2011

U.S. DEPARTMENT OF ENERGY

Fermilab

# Outline

- Introduction
- Many individual topics
- Conclusion

# Introduction Liquid Argon – Why

Liquid Argon is a powerful Scintillator (40,000 photons/MeV) and allows free electrons to drift meters under practical strength electric fields.

It presents an attractive Target Medium for:

Neutrino interactions where liquid Argon TPCs can produce bubble-chamber quality event images;

Dark Matter searches which exploit features of light and free charge produced in Argon by the recoiling nucleus to achieve excellent background rejection.

# Introduction - Some Context (1)

Technique pioneered by ICARUS collaboration over 30 years under C. Rubbia.

Work at Fermilab started by A. Para in ~ 2004

Evolved into significant program at Fermilab, including

- R & D facilities at PAB and the Liquid Argon Purity Demonstration
- ArgoNeuT exposure to NuMI beam
- MicroBooNE experiment (E-974) about to undergo CD-2 review,
- Liquid Argon proposal in the LBNE (Long Baseline Neutrino Expt)
- DarkSide 50 Dark Matter Search
- LArSoft General Software Project for LArTPC detectors

# Introduction - Some Context (2)

Institutions collaborating in hardware R & D:

- Yale - Syracuse (ArgoNeuT construction and exposure)
- Michigan State University (TPC electronics)
- M.I.T and Indiana University (Light readout)
- BNL (TPC electronics and TPC design)
- Princeton (depleted Argon recovery and special cryogenics)
- UCLA (development of infrastructure for QUPID)

# Introduction   Neutrino & Dark Matter Synergies

**Technical Issues for Multi-ton Argon Neutrino detector:**

- Chemical purity to allow electron drift (10’s ppt O2 equivalent),
- Chemical purity to allow light production and propagation
- Cryostat and Cryogenics and associated safety issues
- TPC design
- TPC readout electronics
- HV feedthroughs (>100 kV) and distribution
- Light Detection
- Data Acquisition
- Detector Materials Qualification

# Introduction Neutrino & Dark Matter Synergies

**Technical Issues for Neutrino or DM Argon detector:**

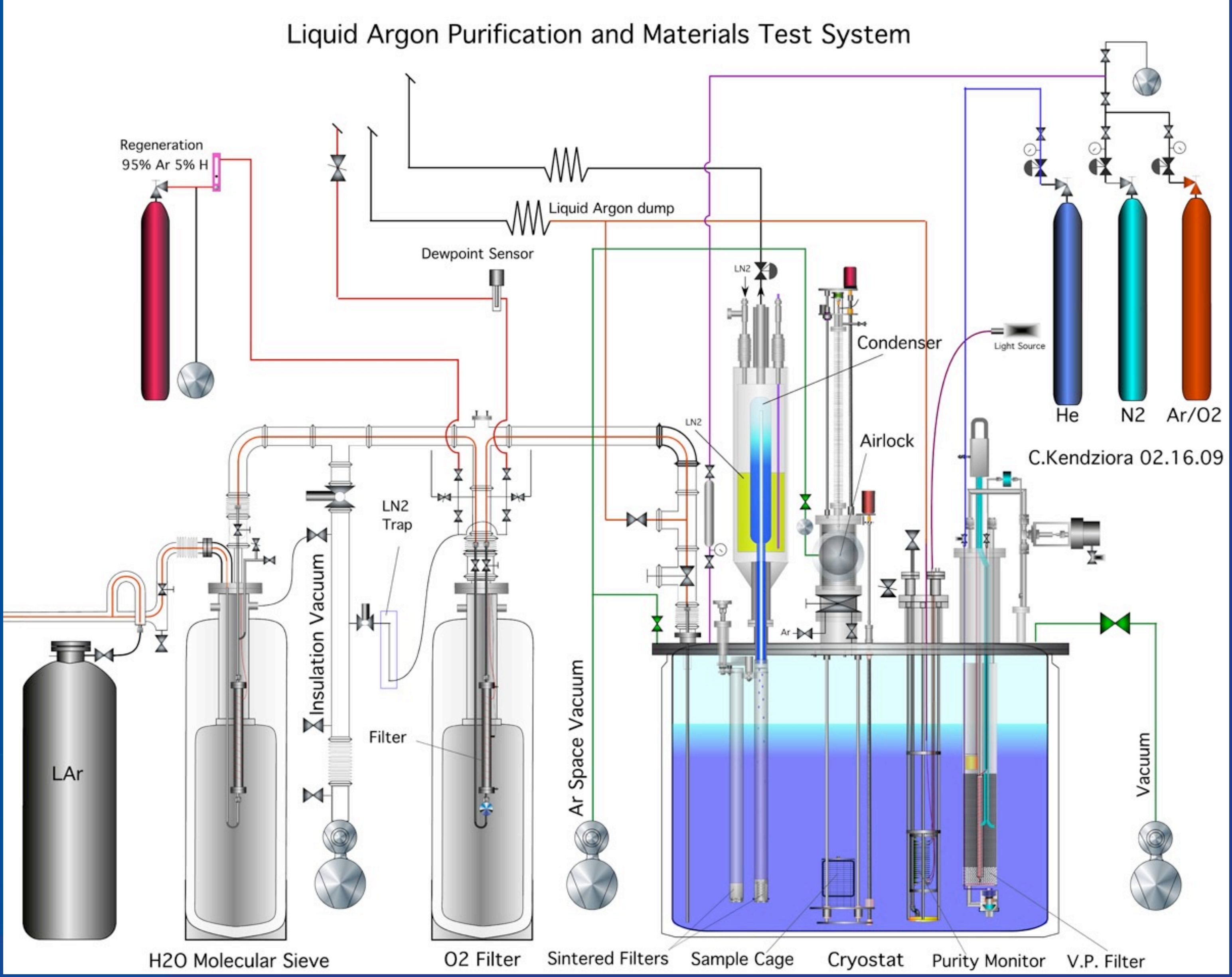
- Chemical purity to allow electron drift (10’s ppt O2), ***($\nu$ and DM)***
- Chemical purity to allow light production and propagation ***($\nu$ and DM)***
- Cryostat and Cryogenics and associated safety issues ***($\nu$ and DM)***
- TPC design ***($\nu$ and DM)***
- TPC readout electronics (*$\nu$)*
- HV feedthroughs (>100 kV) and distribution ***($\nu$ and DM)***
- Light Detection ***($\nu$ and DM)***
- Data Acquisition ***($\nu$ and DM)***
- Detector Materials Qualification ***($\nu$ and DM)***
- Shielding from environment radiation (*DM)*
- Radio-purity of detector materials (*DM)*
- Radio purity of Argon (*DM)*



Fermilab

# Facilities – Liquid Argon Setup at the PAB

# Facilities – Schematic of Materials Test Stand



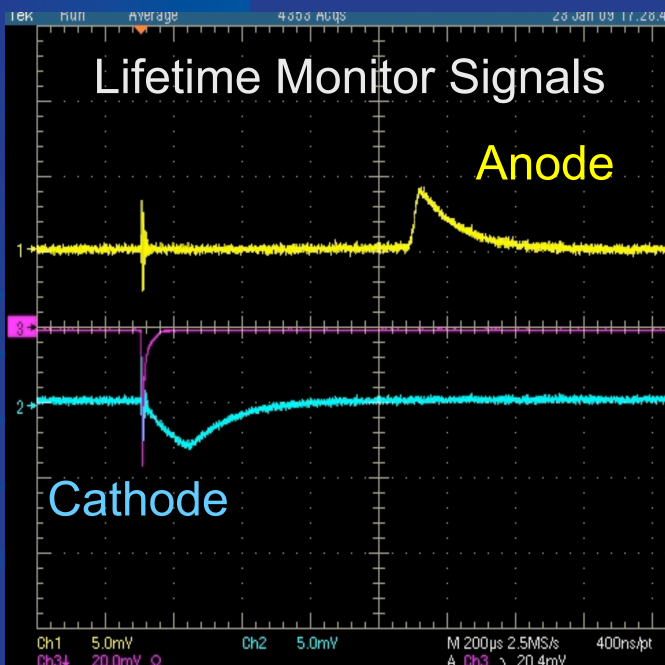
# Liquid Argon Materials Test System Features

**Operation Features of Materials Test System**

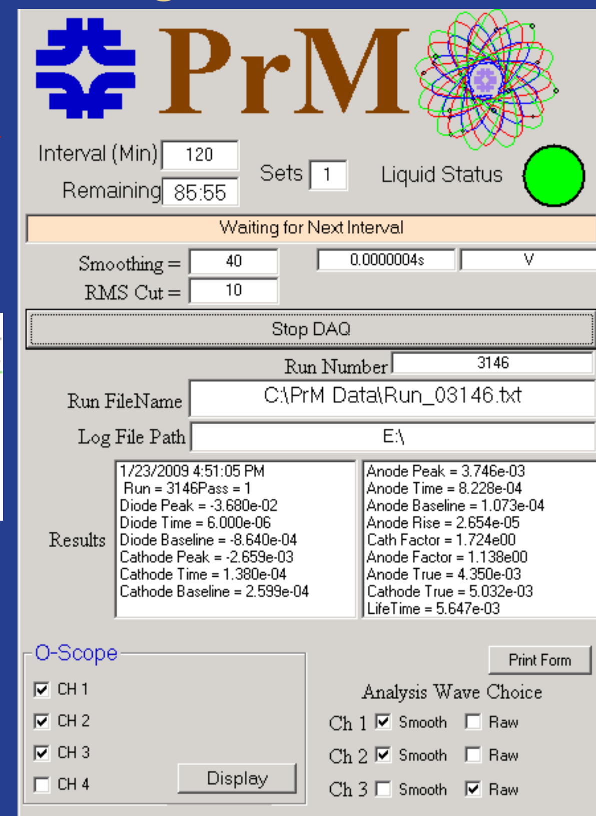
- External Filters regenerated in place
- Can insert materials into known clean argon
- Can insert materials after purging only or after pumping on them
- Can position materials into liquid and into ullage giving range of temperatures
- Can insert known amounts of contaminant gases
- Nitrogen-based condenser can maintain liquid for long (weeks) studies
- Internal filter-pump can remove contamination introduced by materials – 2hr cycle
- Argon sample points at source, after single-pass filters, and in cryostat gas and liquid

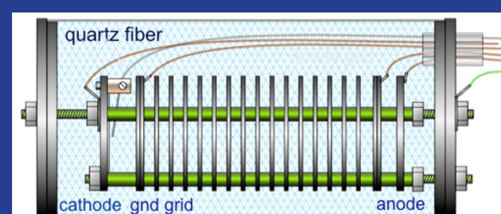
# Measurement Features of Materials Test System

- Measure electron drift lifetime (0.3 milliseconds to 10 milliseconds)
- Measure Oxygen (0.5 ppb sensitivity) with oxygen meter (Delta-F & Tiger Optics)
- Measure H20 in gas (0.5 ppb sensitivity) with water meter (Tiger Optics)
- Cryogenic data, Lifetime Data, analytic instrumentation data in single data-base
- Runs 24/7 unattended - except for filter regeneration and argon refills




Lifetime Monitor Analysis

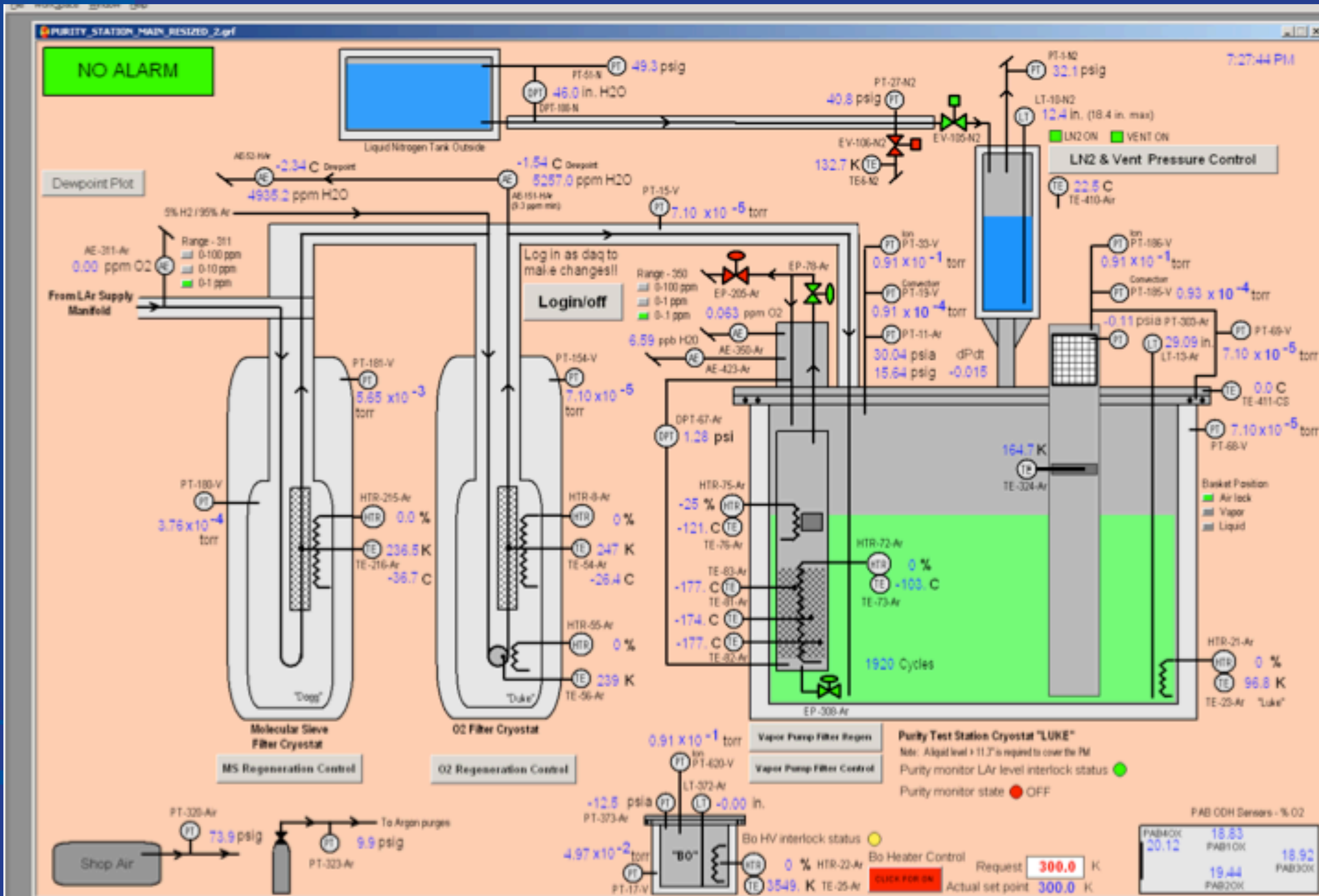



Lifetime Monitor a la ICARUS

# Materials Test Stand Automation

## Cryogenics Control Panel



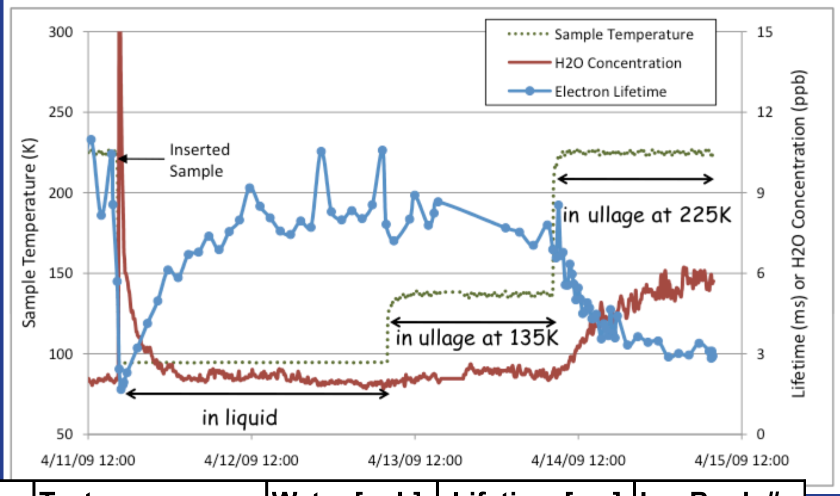





Fermilab

# Materials Test Stand

Typical data




Some data samples

| | Material | Date test started | Preparation | Tests | Water [ppb] | Lifetime [ms] | LogBook # |
|---|---|---|---|---|---|---|---|
| 1 | Cleaning Solution | 6/29/09 | evac. 24 h | vapor/liquid | 4 | 5 | 946 |
| 2 | Vespel | 7/9/09 | evac. overnite | liquid/vapor | 5-7 | 2-5, 4-6 | 960 |
| 3 | MasterBond glue | 7/16/09 | purged 18 h | vapor/liquid | 1.6 | 1.3- 2.9 | 974 |
| 4 | Bostik | didn't pass submerging in the liquid argon | | | | | 992 |
| 5 | LEDs | 7/31/09 | purged 38 h | vapor | 3.5 | 5 | 993 |
| 6 | Carbon filter material | 8/12/09 | evac. 24 h | liquid/vapor | 2 | 4-9 | 1000 |
| 7 | 962 FeedTru Board V2 | 10/12/09 | evac. 24 h | vapor/warm | 85 | 1-5 | 1062 |
| 9 | Teflon cable | 1/9/10 | purged 28 h | warm/liquid/vapor | 8-20 | 2-5 | 1175 |
| 10 | 3M "Hans" connectors | 1/29/10 | purged 46 h | warm/liquid/vapor | 5-12 | 3 | 1198 |
| 11 | 962 capacitors | 3/2/10 | evac. 24 h | warm/liquid/vapor | 6-14 | 3-6 | 1228 |
| 12 | 962 polyolefin cable | 4/12/10 | evac. 16 days | warm | 25-60 | 2 | 1237 |
| 13 | Rigaku feedthrough | 4/20/10 | purged 7.5 h | warm | 15 | 3 | 1250 |
| 14 | Rogers board (Teppei) | 4/23/10 | purged 26 h | warm/liquid/vapor | 40 | 2, 6-10 | 1254 |
| 15 | Arlon Board (Teppei) | 5/14/10 | evac. 0.5 h, pur.2 days | warm/vapor | 300, 80 | 1.3, 3.5 | 1263 |
| 16 | Polyethylene tubing | 5/24/10 | evac. 6 h, pur. 66 h | warm | 300-500 | 1 | 1278 |
| 17 | Teflon tubing | 5/27/10 | evac. 1 h, pur.17 h | warm | 9-13 | 4-5 | 1283 |
| 18 | Jonghee board | 5/28/10 | evac. 6 h, pur. 1.5 h | warm/vapor | 100,28 | 1.2, 5-8 | 1285 |
| 19 | Jonghee connectors | 6/4/10 | evac. 3.5 h, pur. 16 h | warm/vapor | 50 | 2-3 | 1290 |
| 20 | PVC cable | 6/14/10 | evac. 29 h, pur.1 h | warm | 120 | 1-2 | 1296 |
| 21 | Teppei TPB samples | 8/3/10 | purged 26 h | warm | 600-1600 | 0.7 | 1342 |

# Materials Test Stand Summary

## Filter Materials:

Industrial filter materials are capable of removing all electronegative materials (water, oxygen)and producing liquid with >10 milliseconds lifetime.

Data on filter capacity at our requirements are sparse;

Filters can be regenerated many times; we know how - using non-flammable Ar-H mix

## Materials:

Materials immersed in the liquid have no effect on lifetime;

Materials immersed in warm gas volume above the argon have:

- no effect on lifetime if the argon is venting at a certain rate;
- significant effect if the warm gas mixes with the liquid argon directly;
- metal surfaces outgas water vapor at significant rate and ... see above

## Contaminants:

Absent leaks, water is the main concern; it comes from detector materials and the cryostat walls in the warm gas.

`A system to test the effects of materials on the electron drift lifetime in liquid argon and observations on the effect of water' R. Andrews *et al.*, Nucl.Instrum.Meth.A608:251-258,2009.

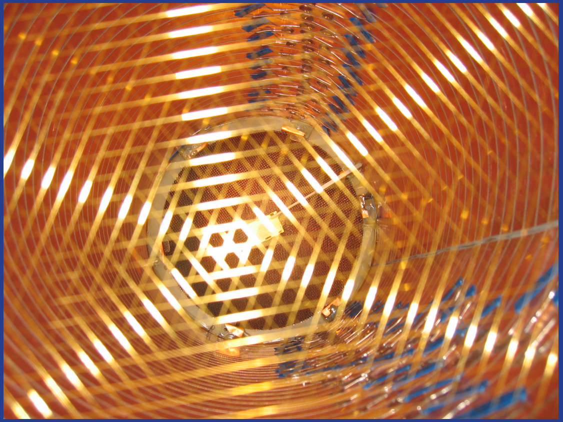
# LAr TPC Electronics Test Stand


1st LAr TPC with U.S. electronics readout

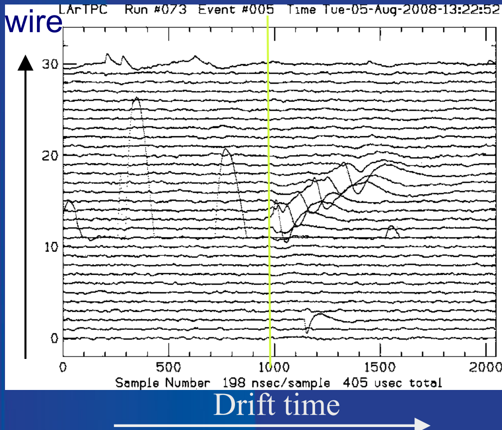
50 cm vertical drift TPC

HV 20 - 30 kV

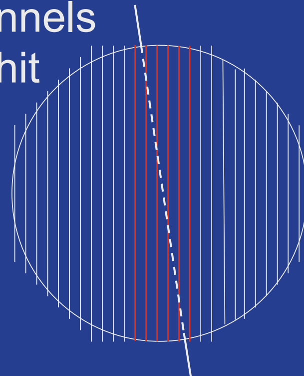
3 planes of wires at $120^0$

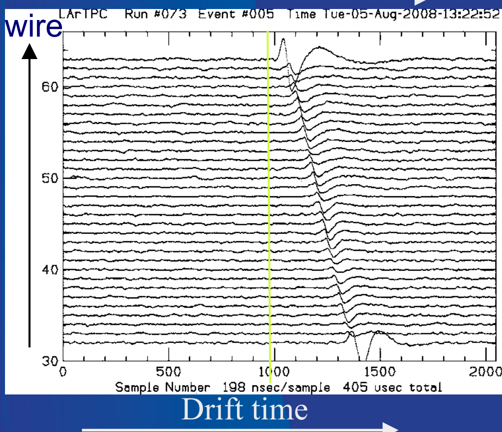


# LAr TPC Raw Signals

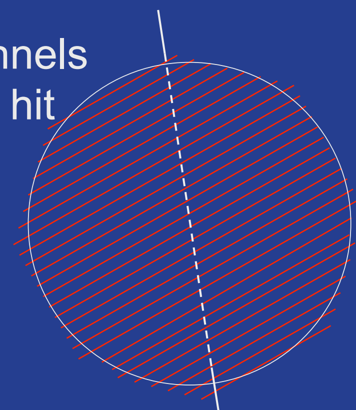


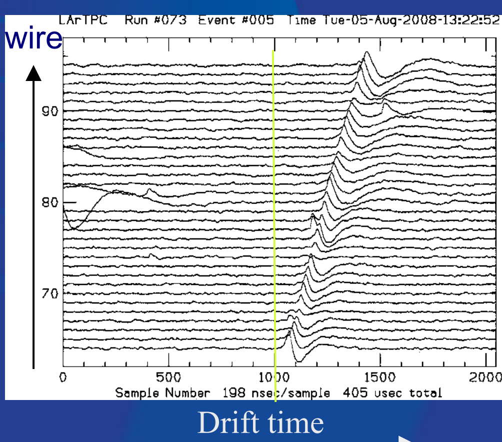

few channels show a hit



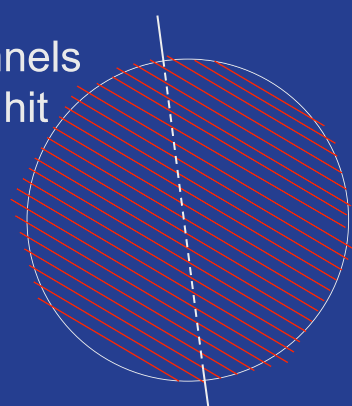



all channels show a hit

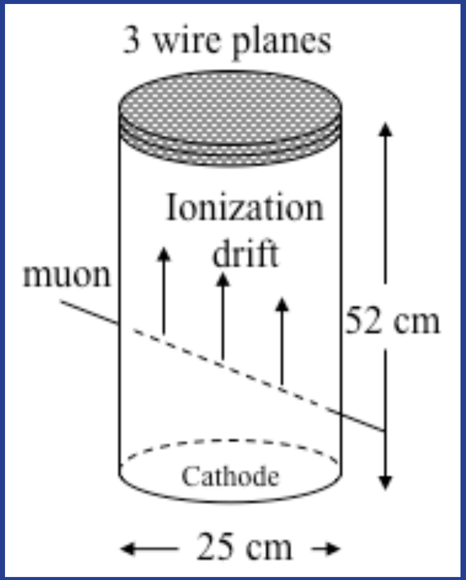




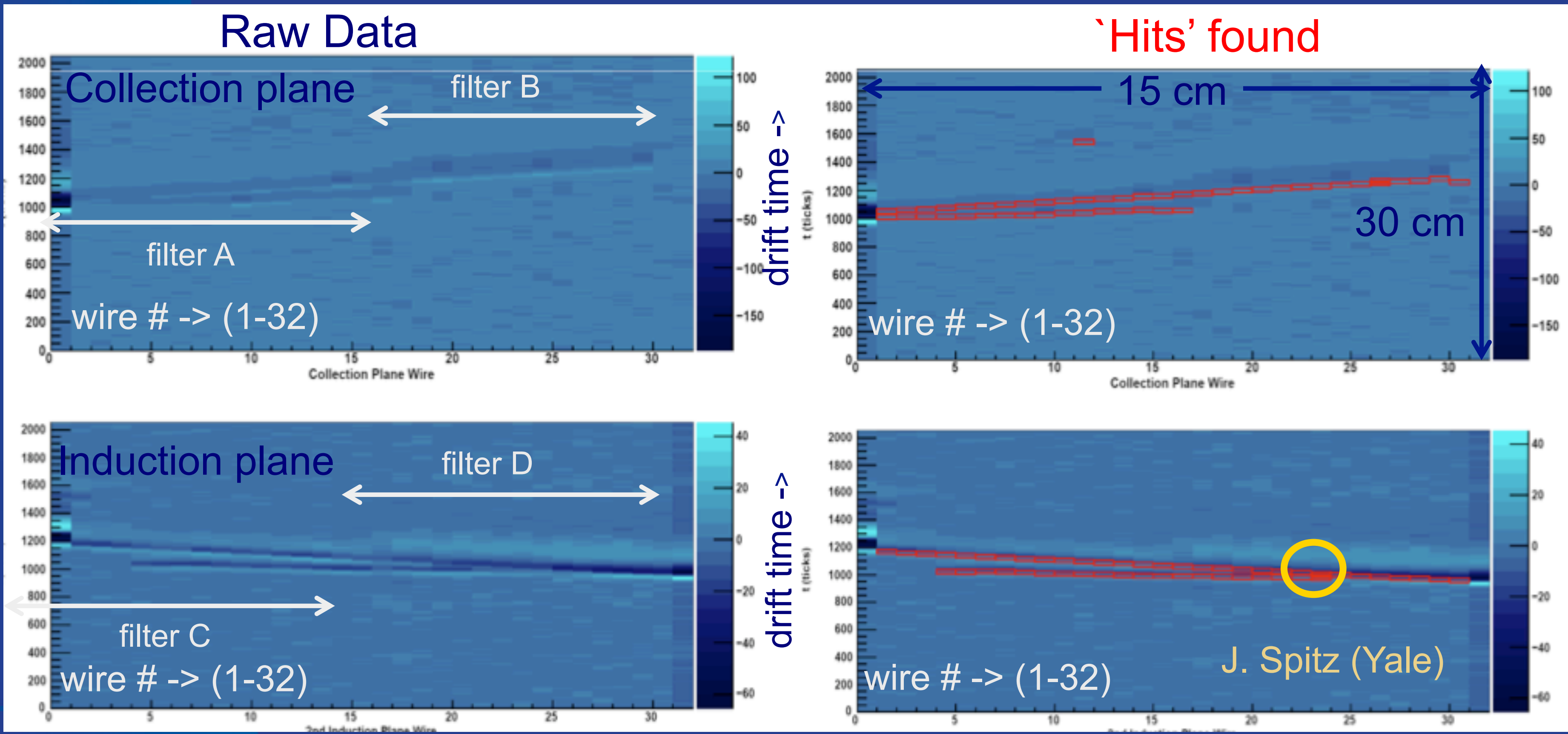

all channels show a hit



Served as the test bed for development of ArgoNeuT electronics, and motivated the development of software hit reconstruction techniques based on FFT.



# Example of use of TPC data – for electronics development




Ionization signals are small (~15,000 e) and slow – important to restrict bandwidth of system. Note the signal region is broader with filters B & D which have acceptance at lower frequency. These sort of data were used to optimize front-end filter bandwidth for resolution and two-track separation.

# Electronics Test System: in-liquid electronics

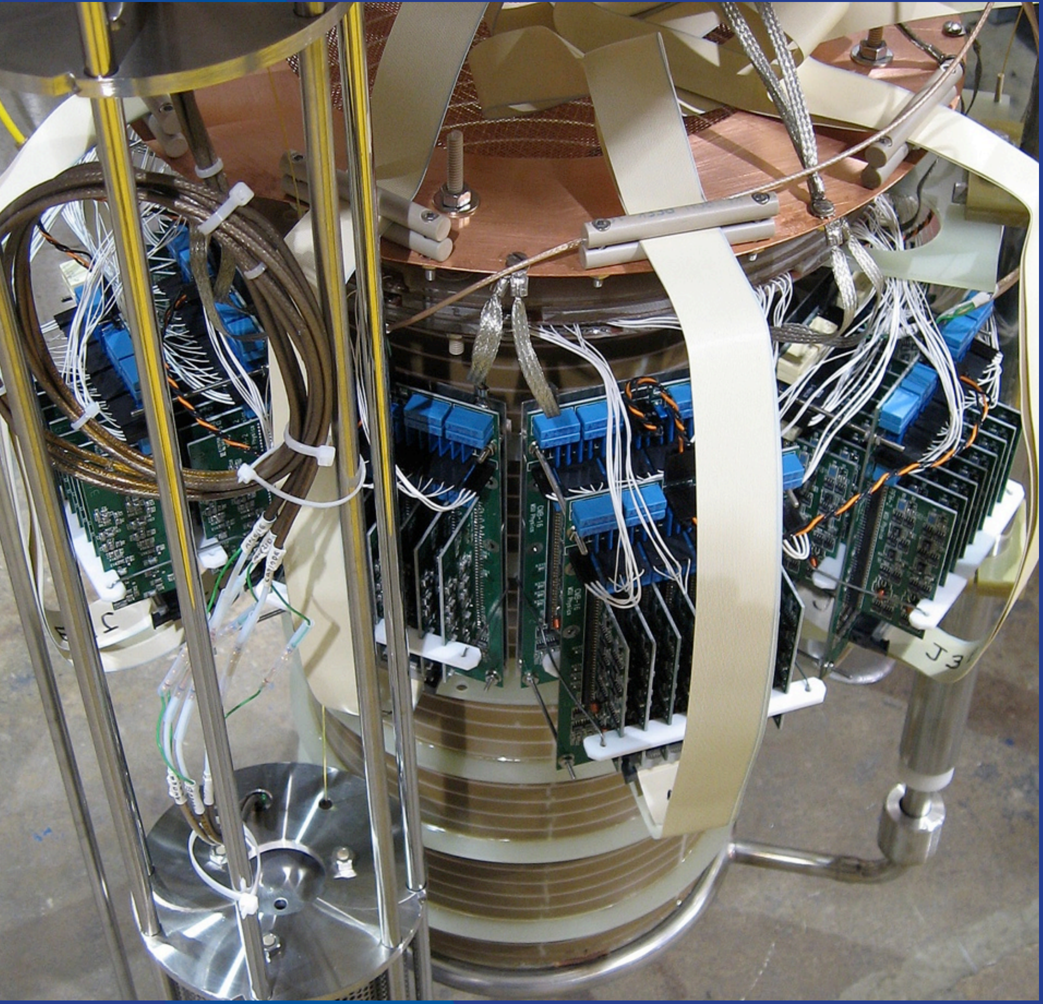
For enormous (multi-kiloton) LAr TPCs, there are significant advantages in being able to put the electronics in the liquid argon and to multiplex the signals before transmitting them out of the cryostat.

Advantages:

- Lower capacitance seen by the first amplifier close to the wire leads to better signal to noise
- Ability to put amplifiers anywhere required avoids either having to bring all signals to top of detector, or to have feed-throughs in liquid.
- Multiplexing signals reduces number of feed-throughs and thus reduces cost and chance of leaks.
- Multiplexing signals reduces cable plant inside detector and thus reduces sources of contamination and out-gassing.

# 1st in-liquid CMOS electronics on a LArTPC

## Built at Michigan State University

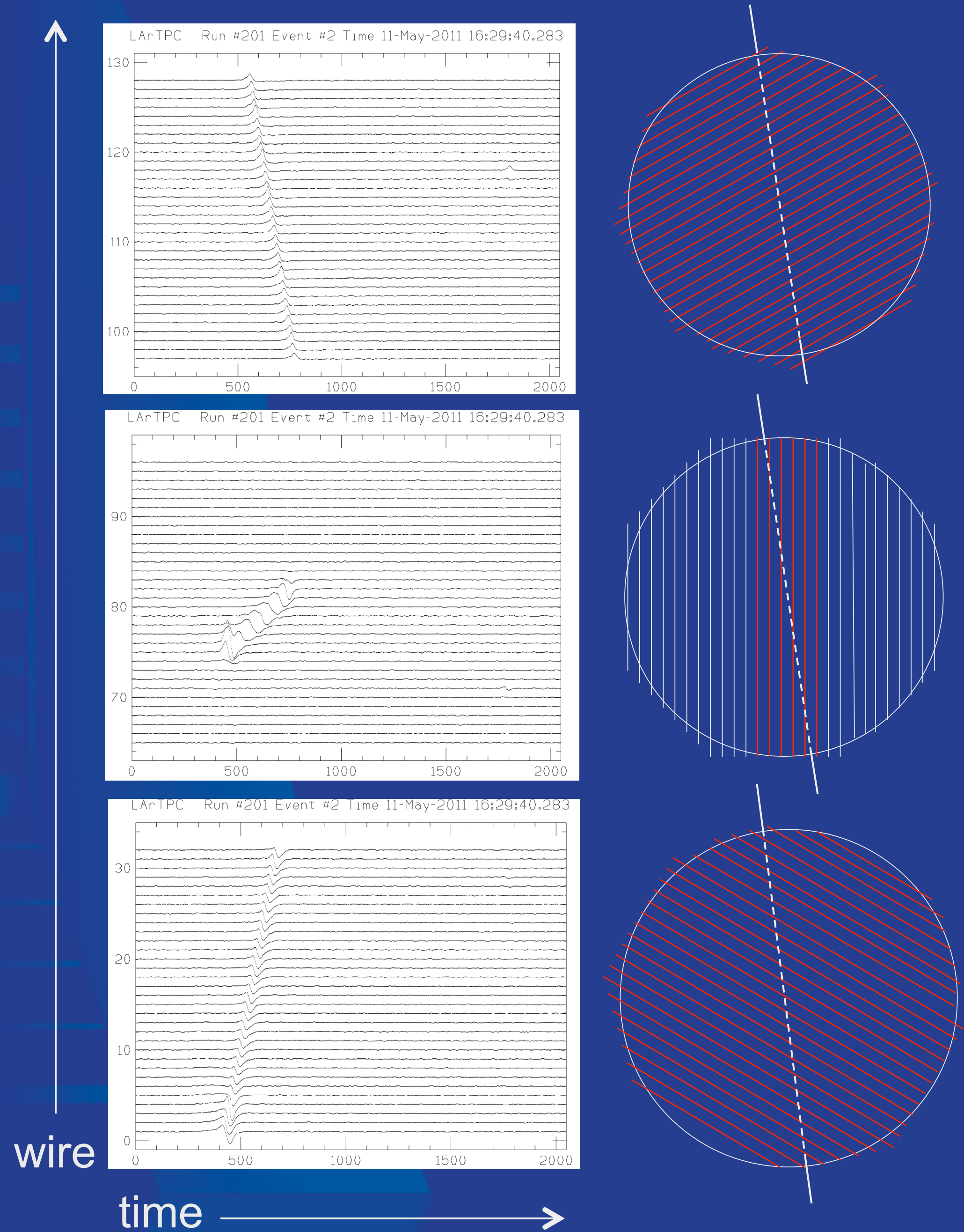


CMOS based design.

- Available technology.
- Operates well at 90K.
- Can be converted into ASIC.

- Capacitors and Inductors require careful selection.
- Connectors and cabling need careful testing.
- Ground connections need robust mechanics.

# In-liquid electronics Raw Data



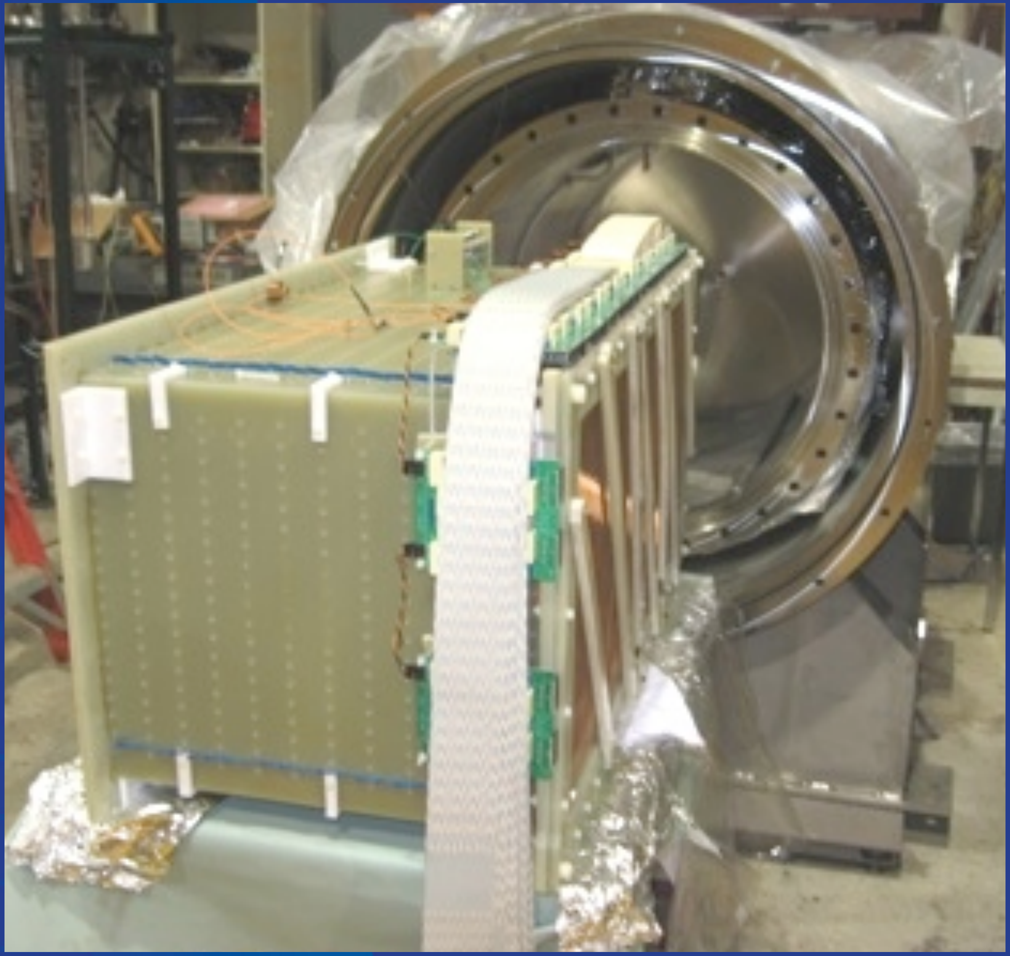

All 144 channels work

S/N looks promising

Analysis in progress

PPD EE dept. looking at long term issues to do with operation at low T

# ArgoNeuT-T962: LArTPC exposed to NuMI Beam



FNAL, Italy, MSU, Syracuse, Yale

1m x 50 cm x 50 cm

2 views +/- $30^0$ to vertical

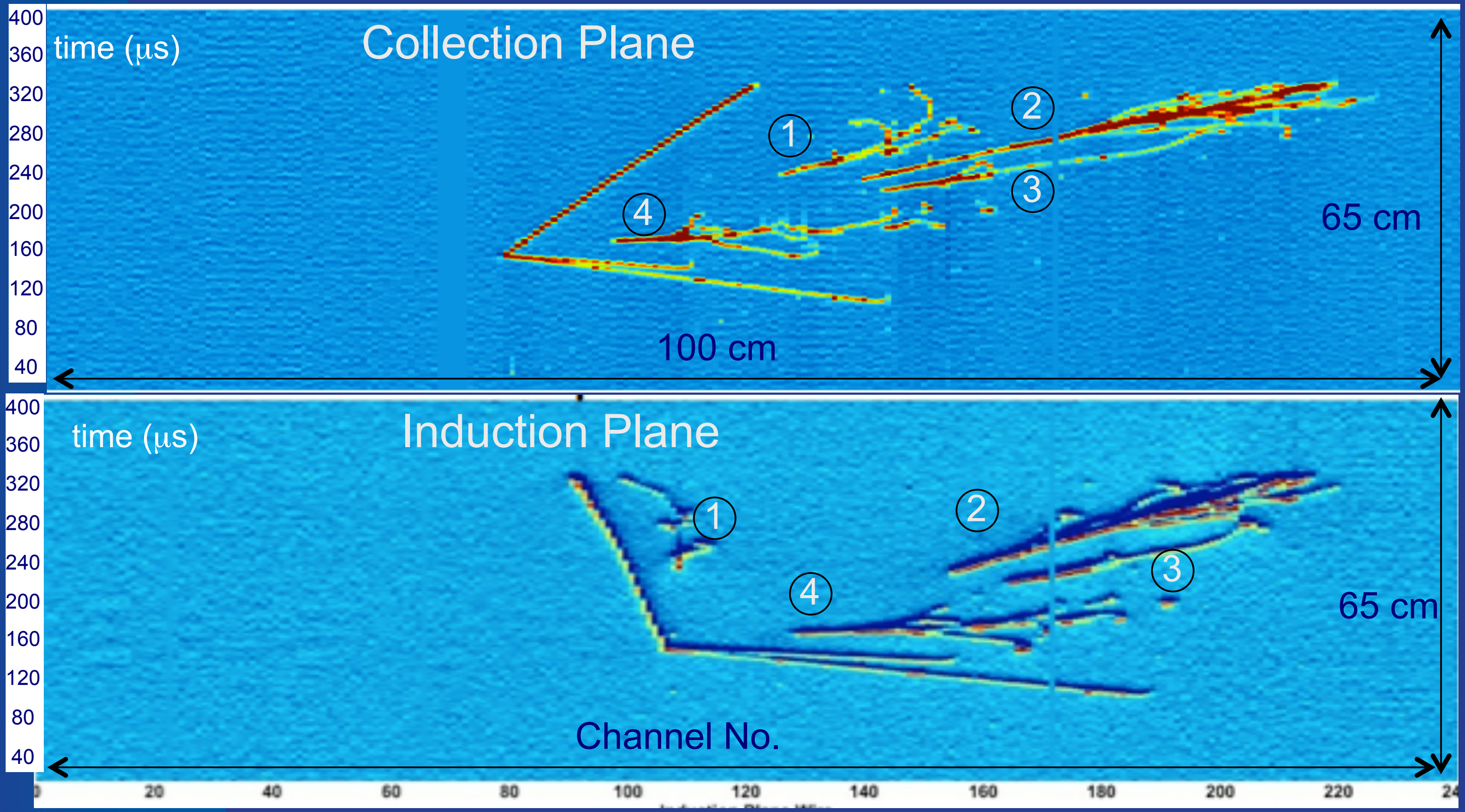
480 channels total

Ran in NuMI beam

neutrino (1 month)

anti-neutrino (4 months)

# ArgoNeuT event with 4 photon conversions




Invaluable data set on $\nu$ interactions in Argon

Analysis in progress – results in Summer

# Achieving good lifetime in an unevacuated vessel

## Liquid Argon Purity Demonstration

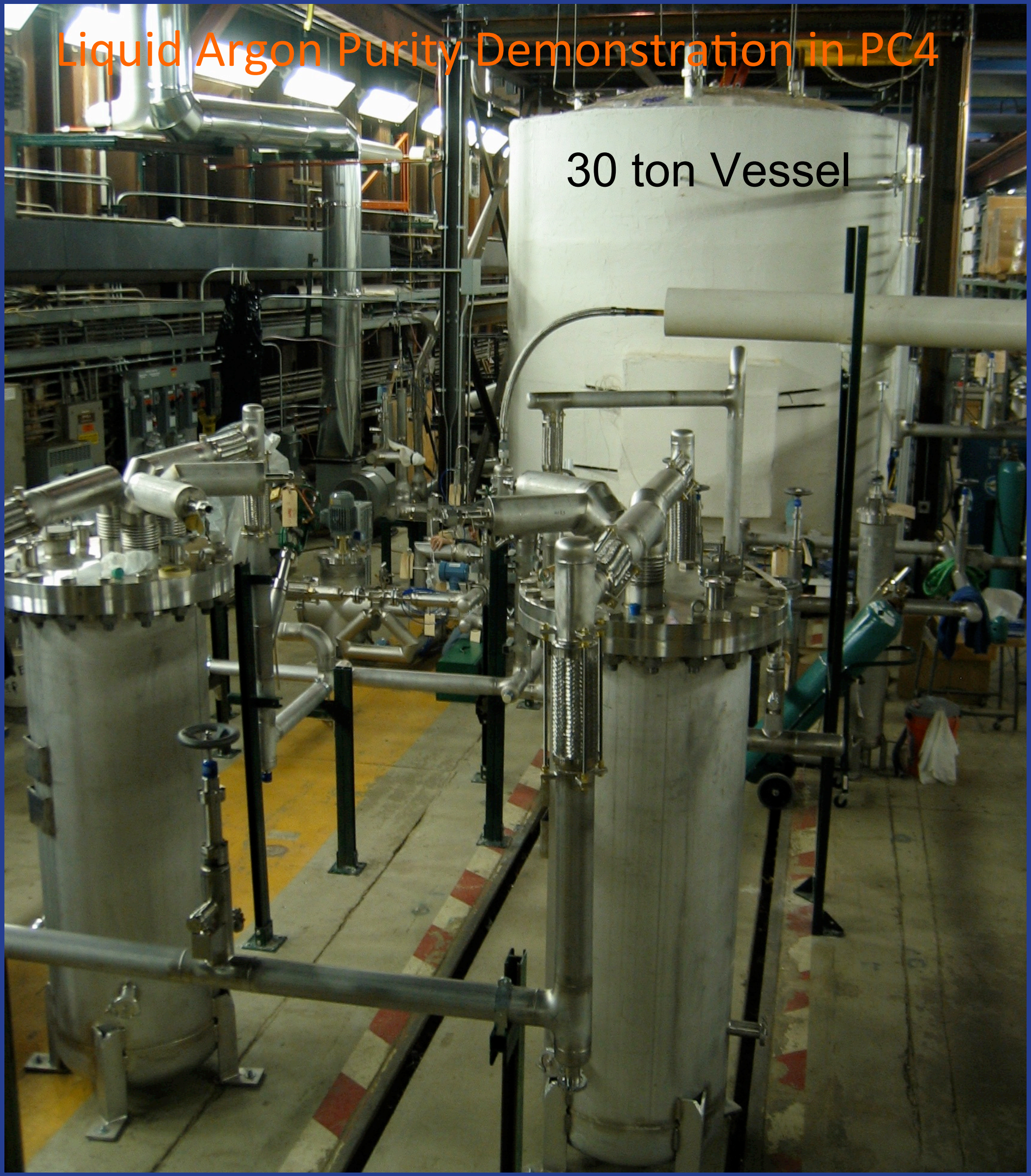
Demonstrate good life-time in an industrial vessel without evacuation. All previous detectors have been evacuated before filling

Atmosphere will be removed by \`argon' piston, then argon gas will be circulated through filters to achieve ~ 1 ppm Oxygen.

Heaters in the insulation can warm the walls to 60 C.

Filtration system sized for 30 tons of Argon at 1 ppm Oxygen. Pump will circulate entire volume in <24hrs.

Expect to start commissioning at the end of May.

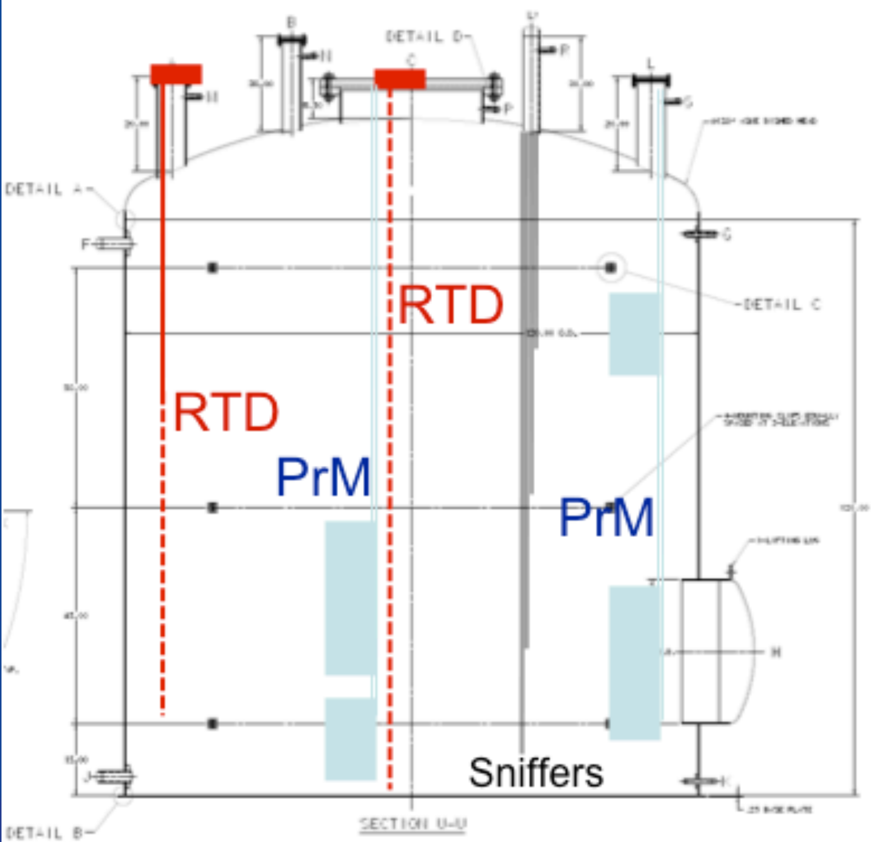


# Electron Drift-Lifetime Measurement and …

Measure evolution of gas-purge using exhaust tubes at different heights (sniffer);

Measure liquid temperatures throughout tank and compare with models to understand convective flow

## Instrumentation for LAPD:




*Analytic Equipment*

Oxygen meters (0.4 ppb sensitivity)

H20 meters (0.5 ppb sensitivity)

N2 meter (20 ppb sensitivity)

*can sample multiple points*

*In the Tank*

2 sets of 2 PrM (20 cm / 60 cm)

2 sets of 3 translating RTDs

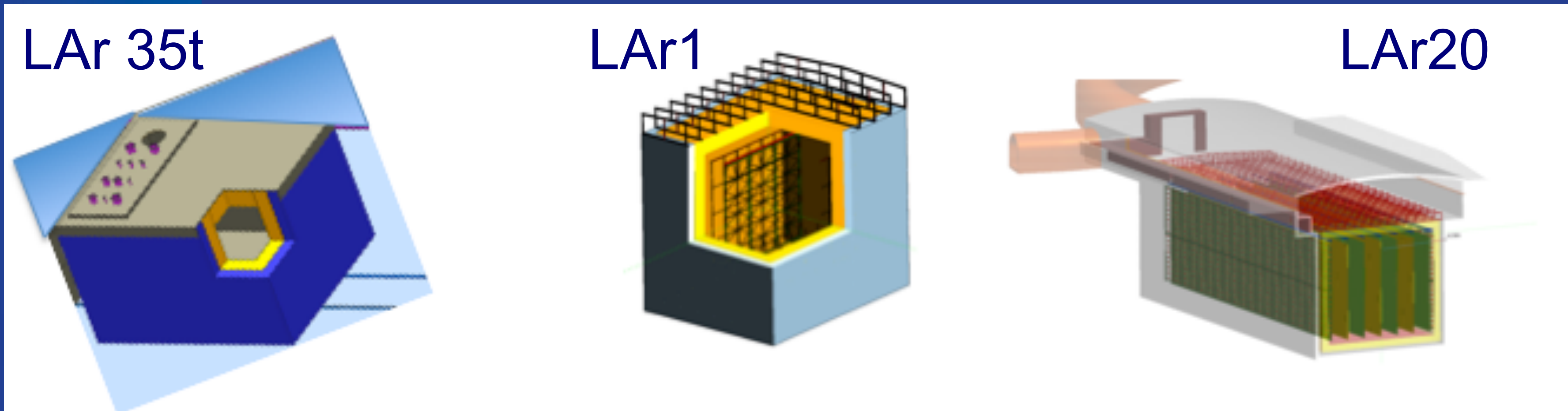
Sniffer set to measure purge evolution

*Inline*

Purity Monitor

Some steps on the path to the LBNE 25 ktonne cryostat based on Membrane panel construction as used in LNG carriers

Well-suited to construction in a cavern.

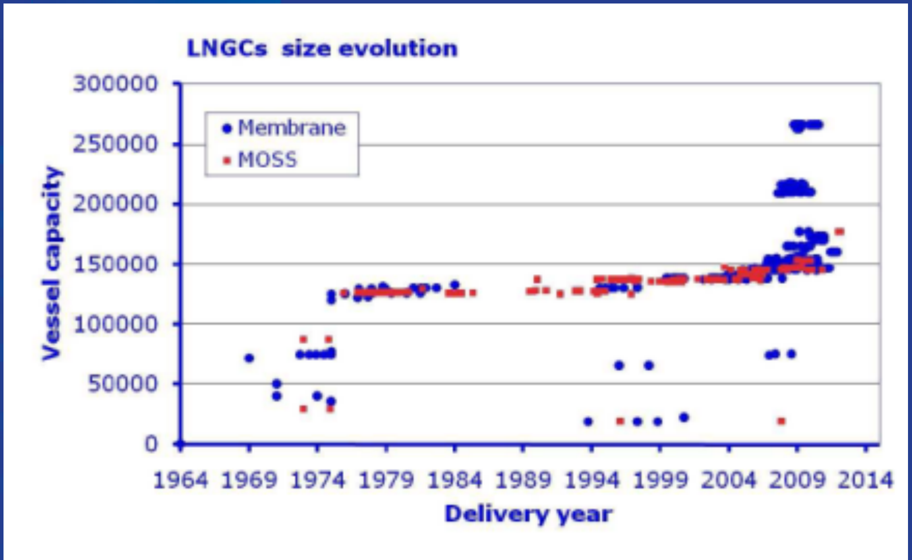



Demonstration of the membrane cryostat technology

Prototype of the LAr20 detector validating TPC design and the assembly procedures.

One module of the LBNE detector

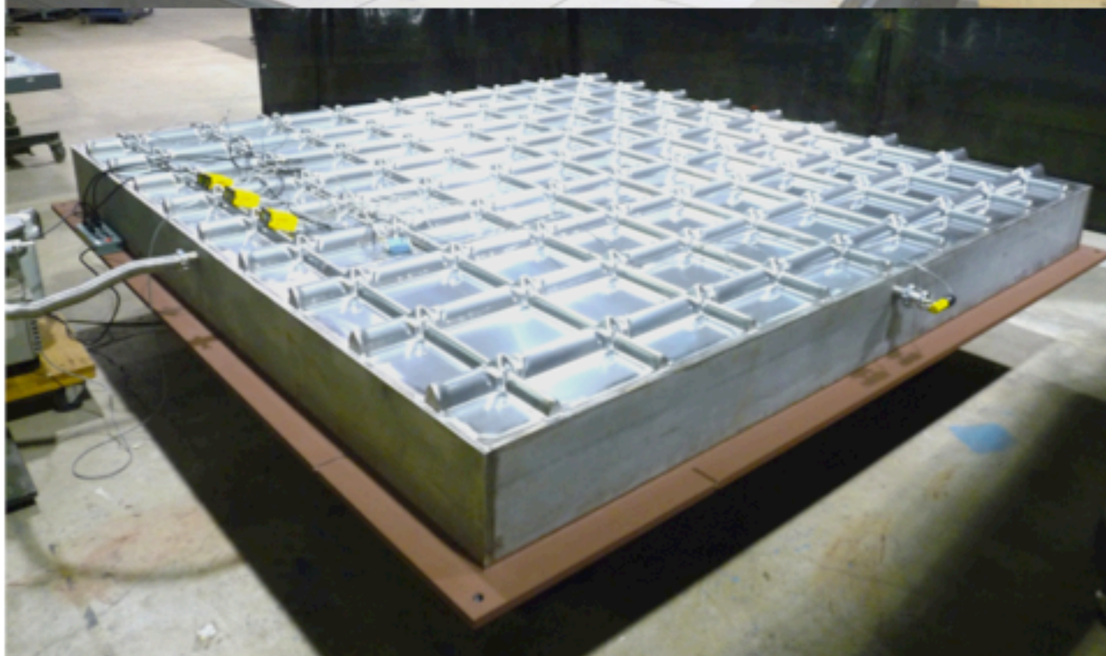
# LNG tanker membrane cryostat

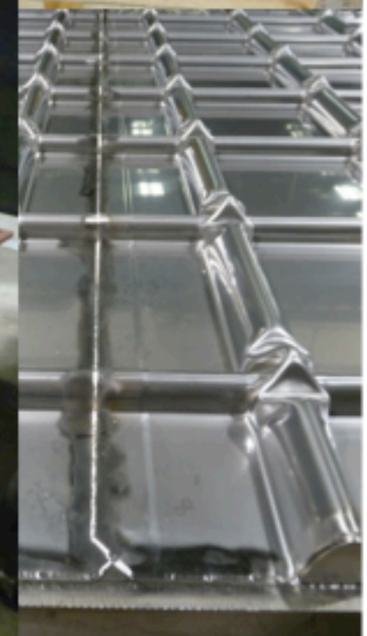



The LNGC "Tembek", one of the thirty-one 216,000 m³ LNG carriers ordered by Nakilat and delivered in 2008

# First steps with the Membrane Technology

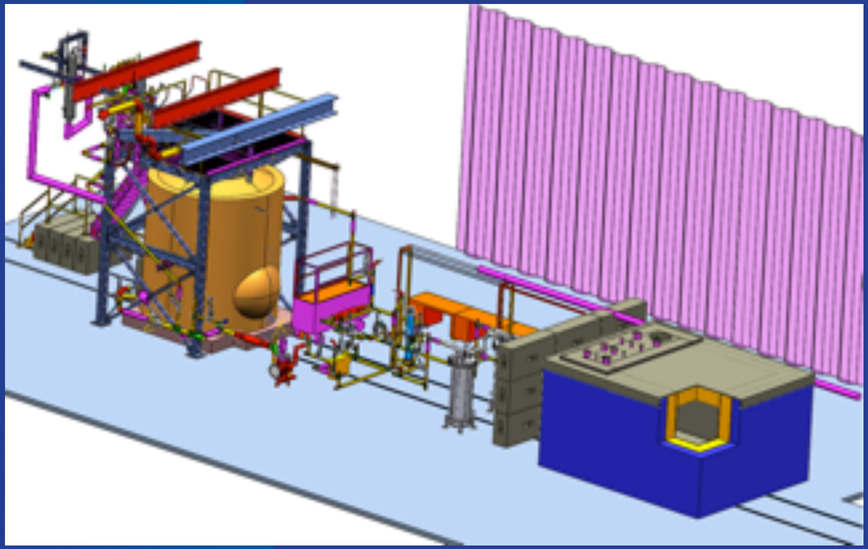
Assembly of first membrane panel showing: delivery crate, (from Korea to Fermilab), insulation backing, weld between two overlapping panes, and 3 panel section ready for leak testing.



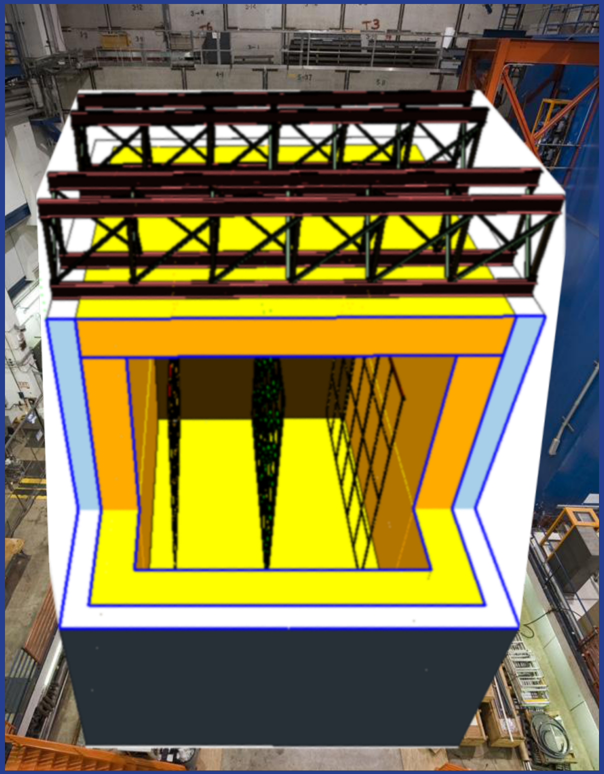


Need some R & D to develop alternative leak-checking procedures to avoid use of contaminating chemicals

# Plans for siting LAr35t and LAr1



Showing the LAr35t cryostat using the same cryogenics and purification system as developed for the Liquid Argon Purity Demonstration



The LAr1 (ktonne) is intended to be built in the DZero pit where there is already significant liquid argon infrastructure.

# Light Readout R & D (M.I.T & Indiana)

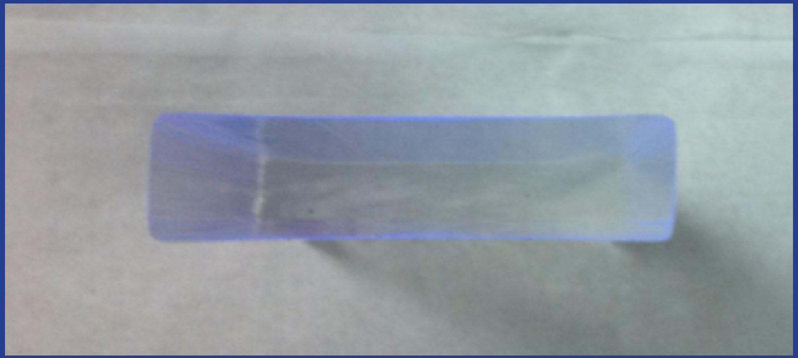
Light signal might be a useful trigger. Argon light is 128 nm and wave-length-shifters (WLS) are used to convert the 128 nm to visible.

Typical arrangement is for PMTs with WLS around the periphery.

This is both costly (paying for PMT area) and inefficient for large volume detectors. Can one wave-length shift and collect light throughout volume and route it to photodetectors?

A concept: clear polystyrene light guide clad with thin layer of WLS in a polystyrene matrix. Issue is attenuation length along the light-guide because of the cladding layer.

A sample of polystyrene bar co-extruded (by the NICADD extruder) with an outside layer of polystyrene containing 1.5% bis-MSB. Note the blue is only evident at the surface, not throughout the volume.



# LAr for Dark Matter: Depleted Argon Distillation Column

Atmospheric Argon contains 1 part in $10^{15}$ of $^{39}Ar$, half-life ~270 yrs, end-point 565 keV.

This gives a background rate of 1 Bq/kg which limits the size of LAr Dark Matter 2-phase TPCs to ~ 1 ton because of dead-time.

The $^{39}Ar$ comes from interactions of cosmic rays on $^{40}Ar$ in the atmosphere. Underground Argon is not subject to these interactions.

Commercial $CO_2$ wells have been found * which contains 400 ppm Argon with <1/25 (measurement limit) the atmospheric concentration.

This Argon represents an unique resource for the Dark Matter program.

After removal of the $CO_2$ a mixture of 3% Ar, 27% He and 74% $N_2$ is obtained. Fermilab Has agreed to host the distillation column designed to separate the Argon.

The basic column was designed at Princeton. It was assembled, safety reviewed and has had its first run at FNAL.


* 2008 J. Phys.: Conf. Ser. 120 042015

# Distillation Column Design and Realization

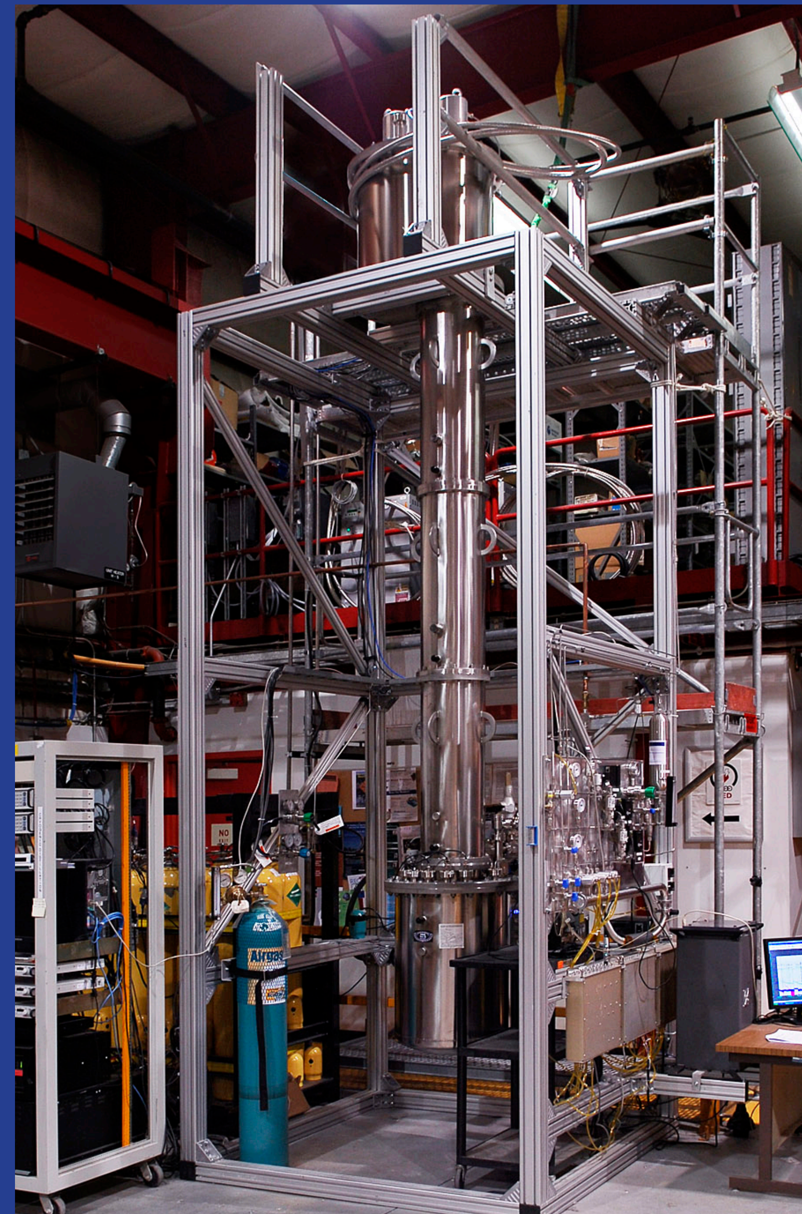
Designed to produce 99.999% pure Ar

Looking up the column

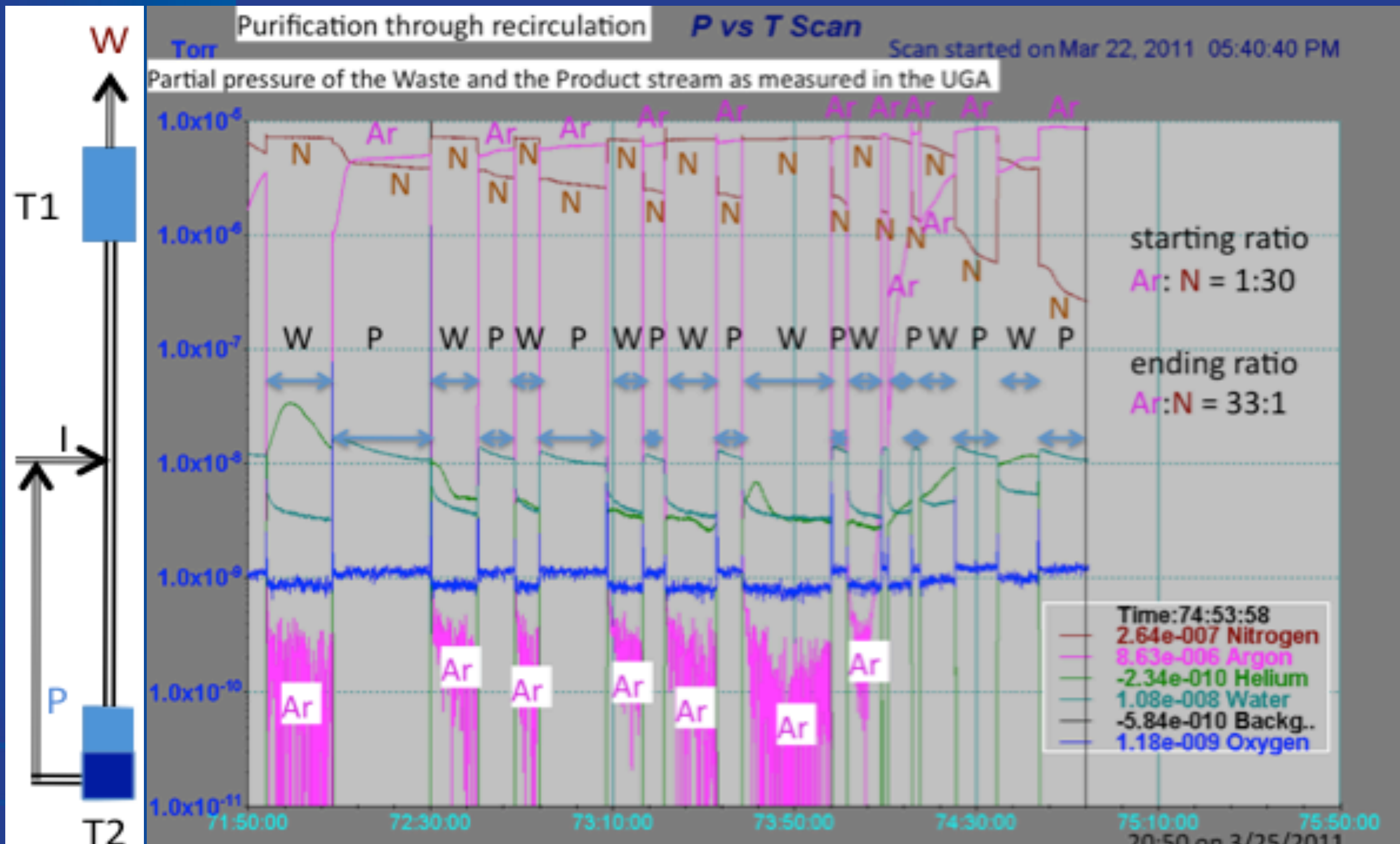
5.5 cm

Column packing material

66 stages



# First Distillation – Batch Mode works




Can distill efficiently but only in batch mode

Upgrades planned to improve cooling at input to achieve continuous distillation

Cryo-Booster (to put Argon into high pressure cylinders) is to be brought online

# One Slide on Software

It is recognized that detector simulation and event reconstruction are important for the success of the Lar technology, and present a significant challenge given the wealth of data the detector provides.

LArSoft is a framework for Detector Simulation and Reconstruction in Liquid Argon TPCs.

It is supported by the Fermilab Computing Division in its ART framework.

It provides many types of event (Cosmic Ray, Neutrino Interaction, Single Particle) and propagates the resultant charge (and light) through the Argon.

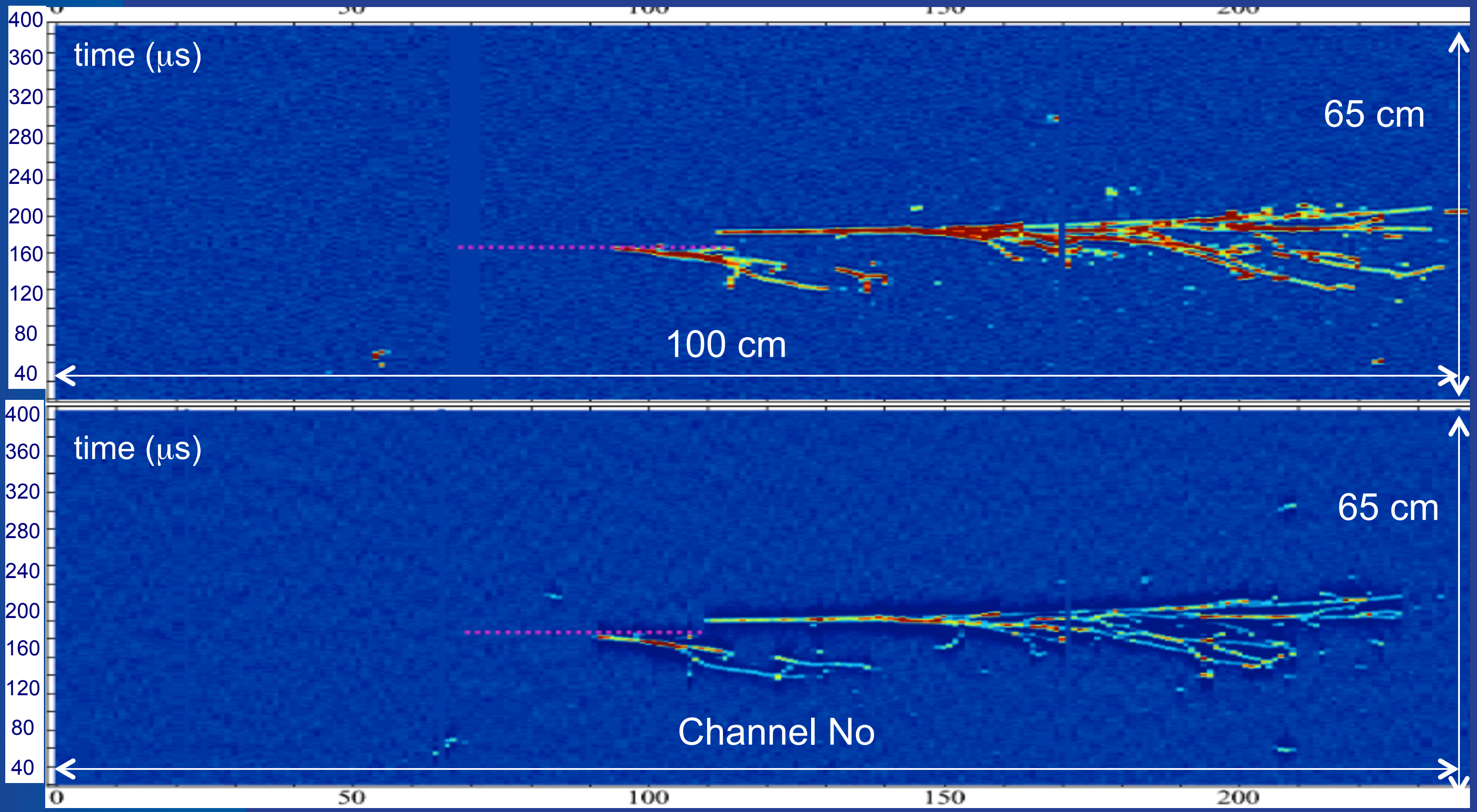
The user defines the detector geometry and signal processing.

LARSoft has contributors from:

Bern (CH), Columbia University, Fermilab, LNGS (It), Kansas State University,

M.I.T., Michigan State University, Syracuse and Yale.

# LArSoft Simulation of a $\pi^0$ in ArgoNeut - cf slide 22



# Conclusions

Vigorous and broad range of activities in Liquid Argon

Stimulating technical challenges and a collaborative environment

Comprehensive program of tests and prototypes towards LBNE and/or other deployment of multi-kiloton detectors

Synergies with Dark Matter searches recognized and exploited

Recognition of the importance of simulation and reconstruction software and a serious commitment to their development.

# Backups

# Introduction Neutrino & Dark Matter Synergies

**Technical Issues for Neutrino or DM Argon detector:**

- Chemical purity to allow electron drift (10's ppt O2), ***($\nu$ and DM)***
- Chemical purity to allow light production and propagation ***($\nu$ and DM)***
- Cryostat and Cryogenics and associated safety issues ***($\nu$ and DM)***
- TPC design ***($\nu$ and DM)***
- TPC readout electronics *($\nu$)*
- HV feedthroughs (>100 kV) and distribution ***($\nu$ and DM)***
- Light Detection ***($\nu$ and DM)***
- Data Acquisition ***($\nu$ and DM)***
- Detector Materials Qualification ***($\nu$ and DM)***
- Shielding from environment radiation (*DM)*
- Radio-purity of detector materials (*DM)*
- Radio purity of Argon (*DM)*

Issues being addressed